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(54) **METHOD OF FABRICATING AN INSULATED GLAZING UNIT HAVING CONTROLLABLE RADIATION TRANSMITTANCE**

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Related U.S. Application Data

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(51) **Int. Cl.**
G01J 1/44 (2006.01)
G02B 26/02 (2006.01)

(52) **U.S. Cl.** .... **250/214 B**; 359/230

(58) **Field of Classification Search** .... 250/214 B, 250/214 AL; 359/230, 231, 601, 265, 266
See application file for complete search history.

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(57) **ABSTRACT**

An insulated glazing unit has controllable radiation transmittance. Peripheries of first and second glazing panes are attached and spaced apart facing each other and then attached to a supporting structure. A conductive layer is atop the first glazing pane inner surface as a fixed position electrode. A dielectric is atop the conductive layer. A coiled spiral roll, variable position electrode is between the first and second glazing panes, a width of its outer edge attached to the dielectric. A first electrical lead is connected to the variable position electrode's conductive layer. A second electrical lead is connected to the conductive layer atop the first glazing pane. Applied voltage between the first and second electrical leads creates a predetermined potential difference between the electrodes, and the variable position electrode unwinds and rolls out to at least partially cover the first glazing pane, at least reducing the intensity of passing radiation.

27 Claims, 5 Drawing Sheets

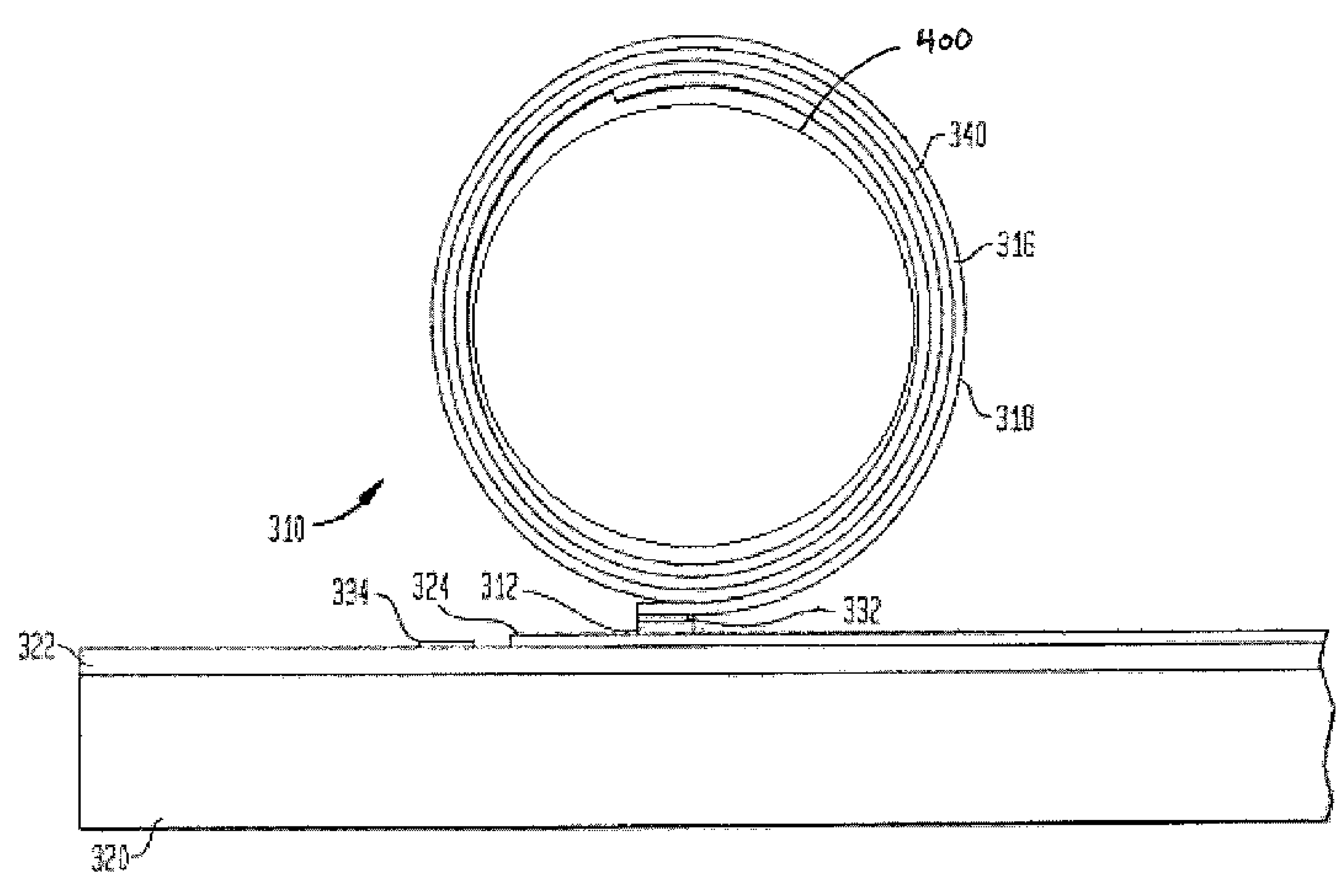

FIG. 1

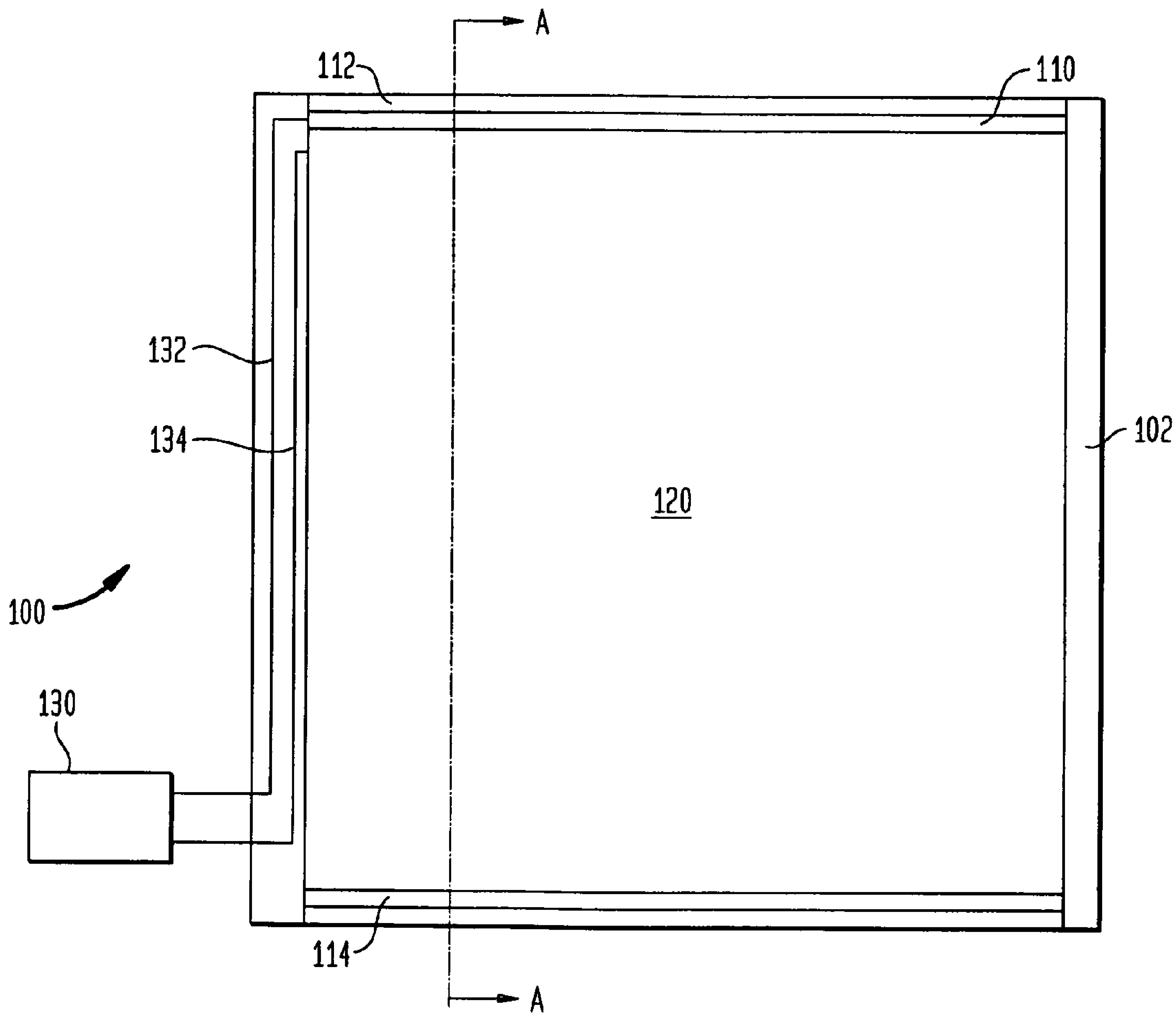

FIG. 2b

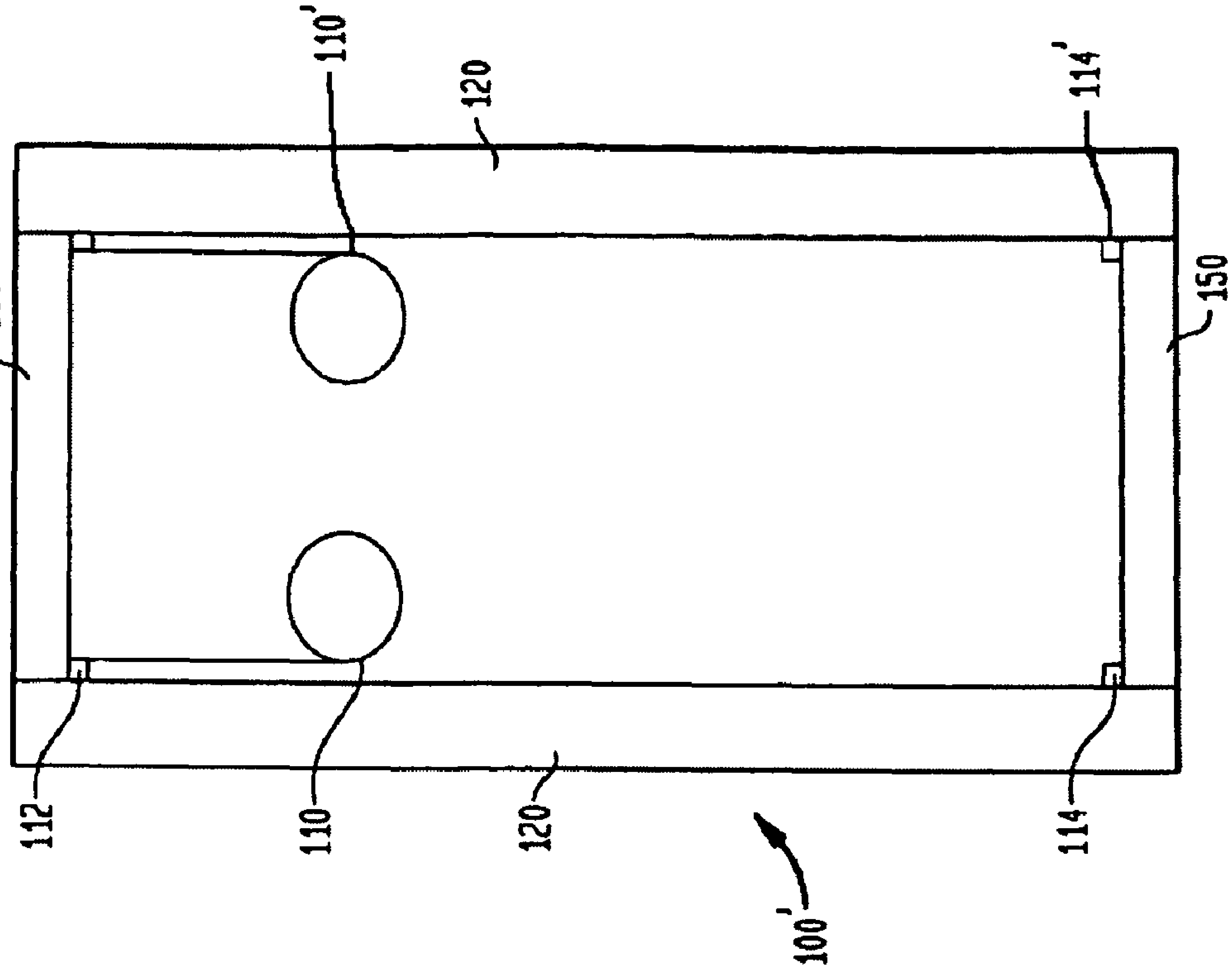
110'
120
114'
150
150
112
110
120
114
100'

FIG. 2a

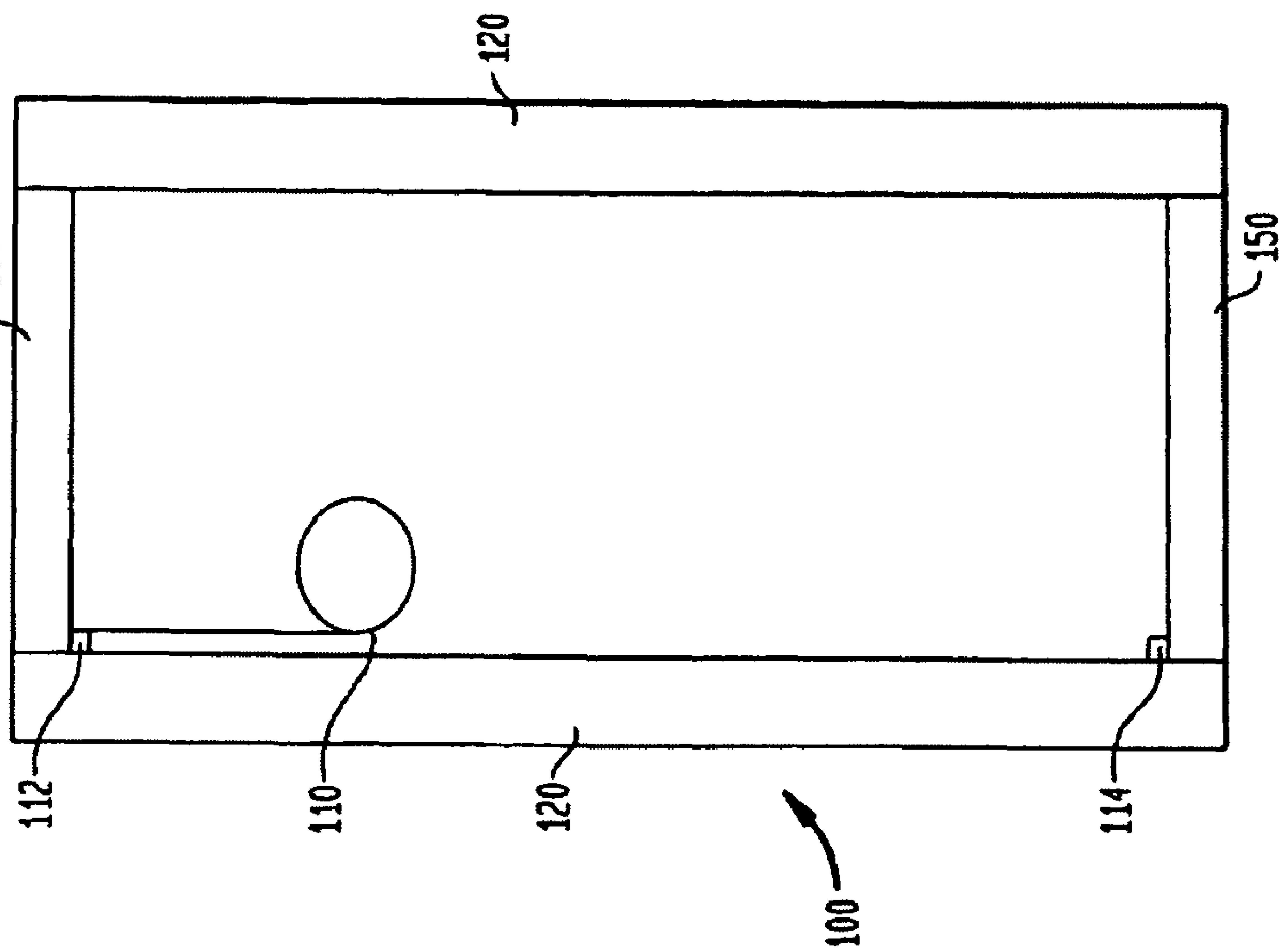
120
150
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FIG. 3a

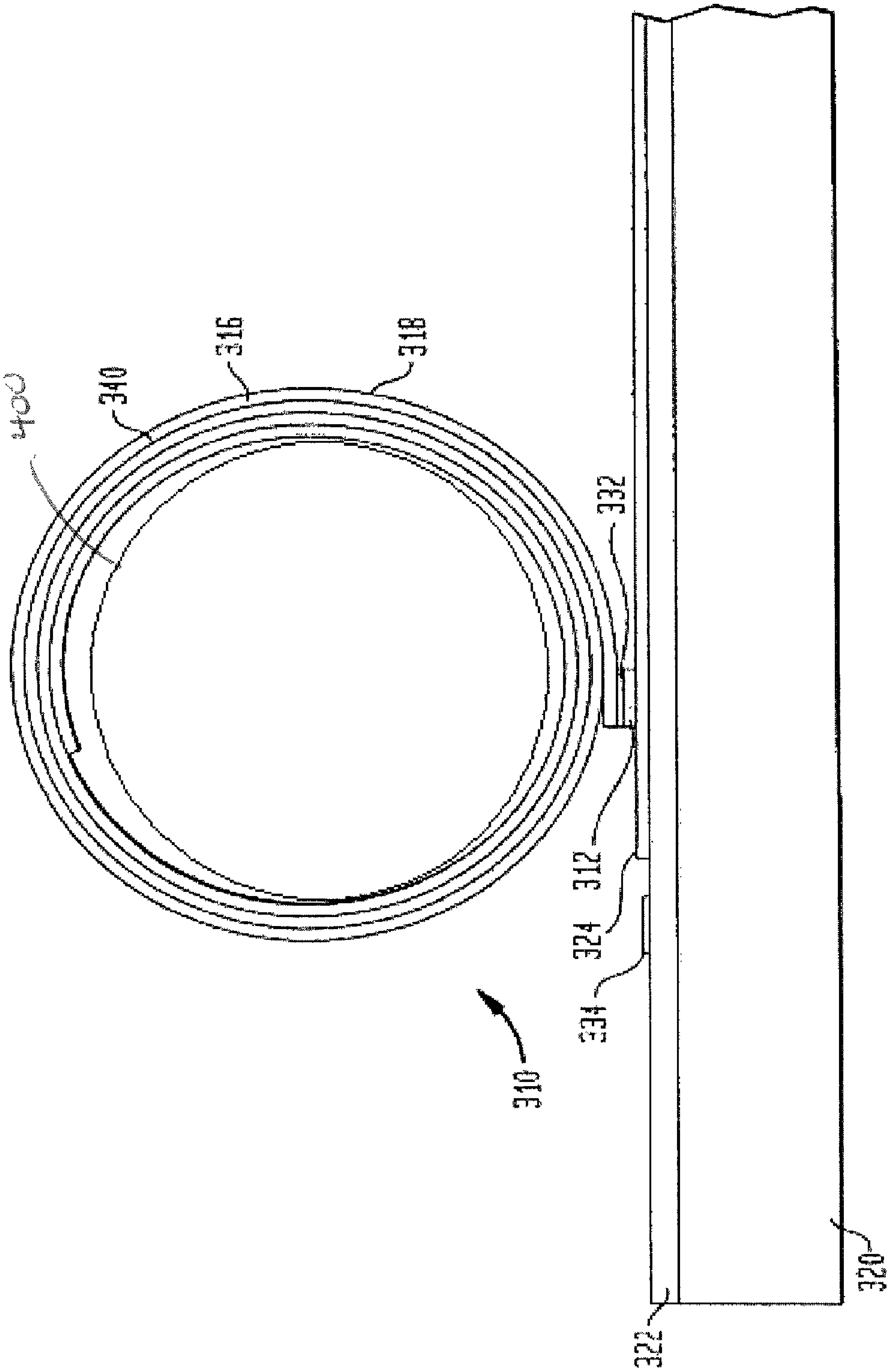


FIG. 3b

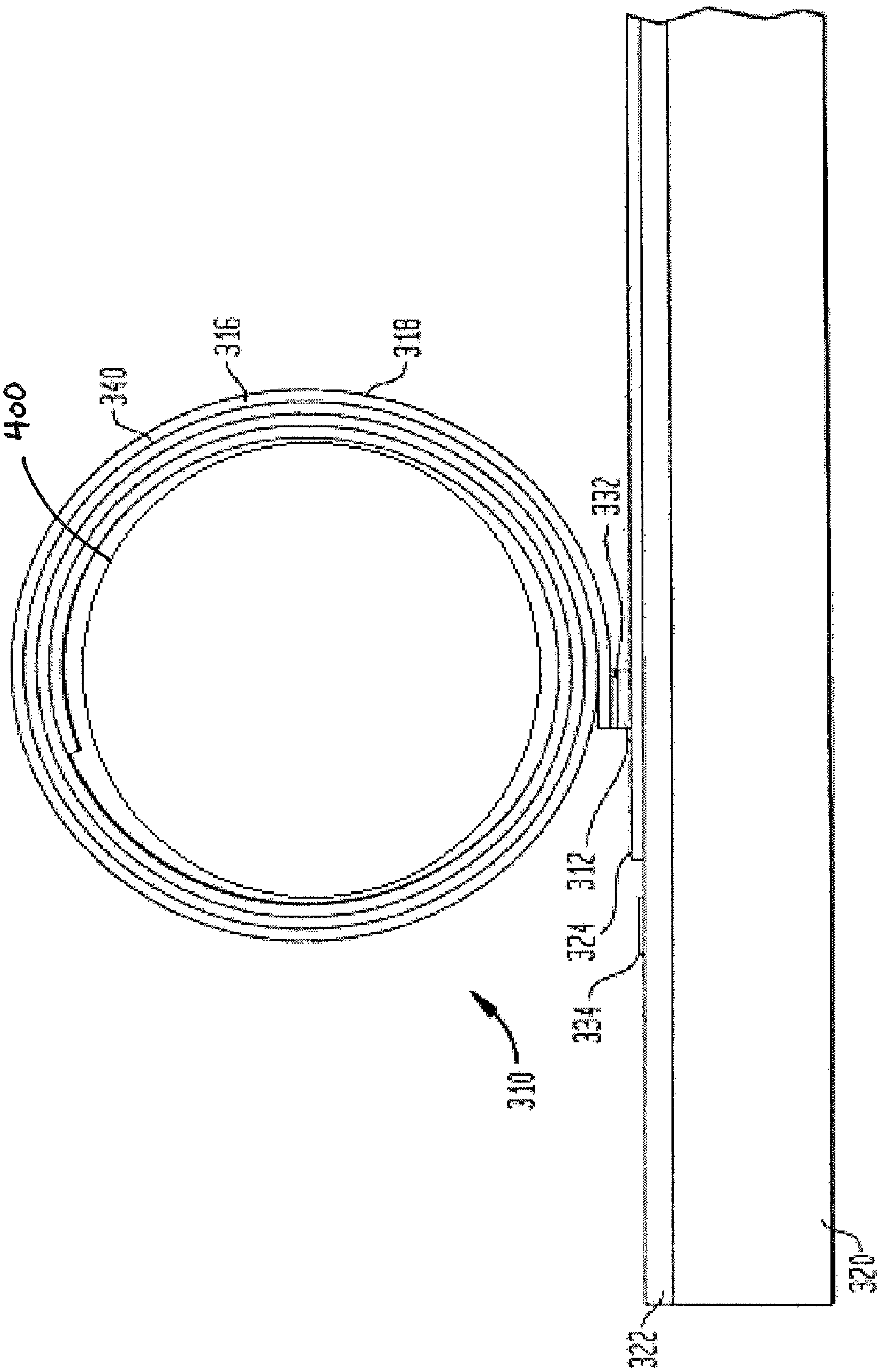
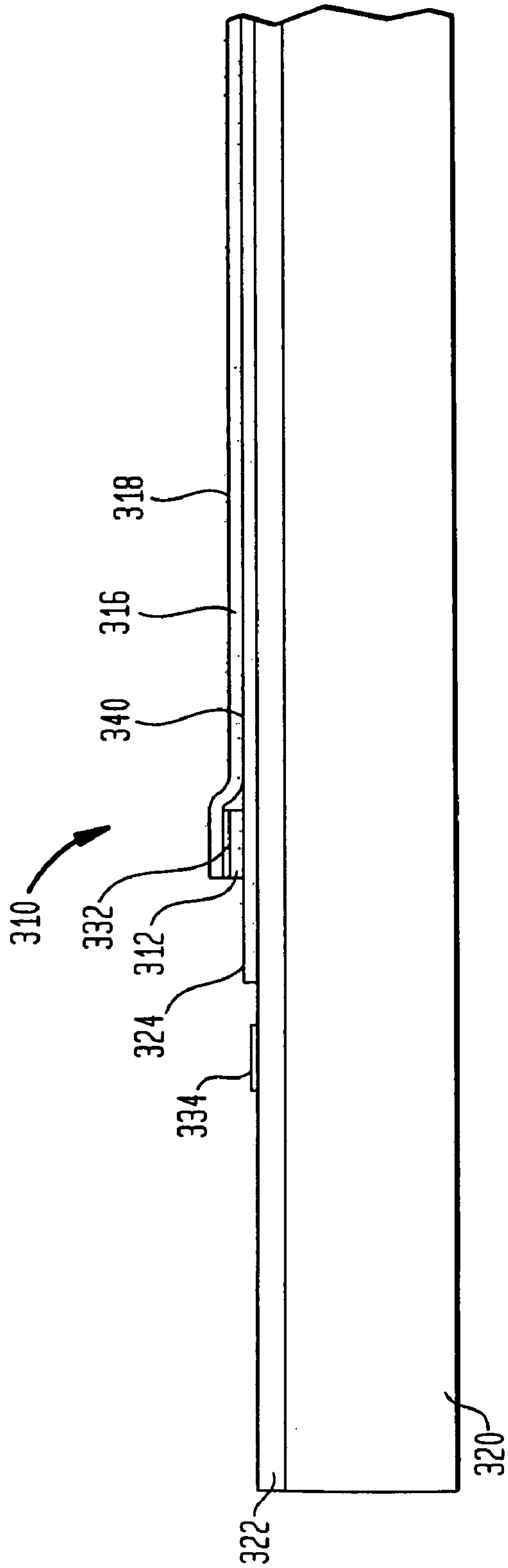


FIG. 4



METHOD OF FABRICATING AN INSULATED GLAZING UNIT HAVING CONTROLLABLE RADIATION TRANSMITTANCE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 11/825,363, filed Jul. 6, 2007 now issued as U.S. Pat. No. 7,645,977, which claims the benefit of the filing date of U.S. Provisional Application No. 60/859,637, filed Nov. 17, 2006, the disclosures of which applications are hereby incorporated by reference herein.

BACKGROUND OF THE INVENTION

The invention relates to an insulated glazing unit (IGU) and its manufacture and, more particularly, to an IGU which includes an electronic physical shutter device that controls the intensity of radiation passing through the insulated glazing unit and/or that can block the radiation passing through the insulated glazing unit.

Glass windows, skylights, doors, and the like which are used in buildings and other structures are known to waste large amounts of energy. The windows permit the infrared radiation of sunlight to pass into the interior of the building and cause unwanted heating, particularly during summer months, thus requiring increased use of air conditioning to remove the unwanted heat. The windows also permit heat to leave the interior of the building during winter months, thereby requiring additional heating of the building. The increased use of air conditioning and heating increases the costs of operating the building and causes increased consumption of petroleum products and other non-recoverable resources. The increased consumption of these resources has become particularly critical as, for example, supplies of petroleum decrease and the price of petroleum rises. Also, at the same time that this increased consumption has become critical, new constructions of residential and commercial structures incorporate more glass than was used in older constructions, thereby further increasing consumption of these non-recoverable resources.

A known method of attempting to reduce the passage of radiation through a window is to use low emissivity glass, tinted or non-tinted, commonly known as Low E glass, which typically incorporates one or more metal based coatings. During winter months, the Low E glass reduces heat loss from the building through the windows by reflecting heat back into the interior of the building. During summer months, the Low E glass reduces interior heating of the building by preventing solar radiation from passing through the windows into the building and also reduces potential damage from the solar radiation. Tinted coatings are frequently added to the Low E glass to enhance its effectiveness. Unfortunately, the use of tinted Low E glass also requires a significant and undesirable trade-off between its optical clarity and its effectiveness in reducing the passage of heat and radiation through the tinted Low E glass. Specifically, the Low E glass requires thicker coatings to more effectively conserve energy, and such thicker coatings cause less light to pass through the window.

Another known approach uses an insulated glass (IG) window that incorporates one or more functional electronic layers between the two or more sheets of glass of the IG window. The electronic layers are somewhat clear in the absence of an applied voltage and allow heat and radiation to pass. When the voltage is applied, the electronic layers darken to reduce the passage of the heat and radiation. The materials used, such as liquid crystal layers, electrophoretic layers, and/or electrochromic layers, are also used in display devices. The electrochromic layers are the materials most commonly used for such electronic layers. An example of this approach is described in U.S. Pat. No. 6,972,888, titled "Electrochromic Windows and Method of Making the Same" and issued Dec. 6, 2005 to Poll, et al., the disclosure of which is incorporated herein by reference.

Undesirably, IG windows that incorporate functional electronic layers are difficult and costly to manufacture, have a questionable operating life, have undesirable operating temperatures, have very slow response times, provide incomplete darkening, and increase power consumption by their operation.

It is therefore desirable to reduce the passage of heat and radiation through a window or the like in a manner that avoids the tradeoffs and drawbacks of the above known approaches. It is further desirable to provide a manufacturing process for such windows that can be used by traditional manufacturers of window glass, thereby adding another economic advantage to the manufacture of such windows.

SUMMARY OF THE INVENTION

According to an aspect of the invention, an insulated glazing unit has controllable radiation transmittance. A first glazing pane is attached at its periphery to a second glazing pane with a spacer separating them, the resultant assembly being attached at its periphery to a supporting structure. The first glazing pane and the second glazing pane are arranged such that an inner surface of the first glazing pane and an inner surface of the second glazing pane face each other and are spaced apart from each other. A conductive layer is disposed atop the inner surface of the first glazing pane and forms a fixed position electrode. A dielectric layer is disposed atop the conductive layer. A variable position electrode is disposed between the first glazing pane and the second glazing pane and is configured as a coiled spiral roll. An outer edge of the coiled spiral roll is attached along a width thereof to the dielectric layer. The variable position electrode includes a resilient layer and a further conductive layer. A first electrical lead is connected to the conductive layer of the variable position electrode, and a second electrical lead is connected to the conductive layer atop the inner surface of the first glazing pane. When a voltage is applied between the first electrical lead and the second electrical lead and creates a predetermined potential difference between the fixed position electrode and the variable position electrode, the variable position electrode unwinds and rolls out to cover at least part of the first glazing pane and thereby at least reduces the intensity of radiation passing through the insulated glazing unit.

In accordance with the above aspect of the invention, at least one of the first electrical lead and the second electrical lead may be connectable to an external power source. A switch may be included that is operable to apply and remove the voltage between the first electrical lead and the second electrical lead. A sensor may be incorporated that is operable to sense one or more of temperature and radiation intensity and that is operable to apply and remove the voltage between the first electrical lead and the second electrical lead based on the sensed temperature or the sensed radiation intensity.

Also in accordance with this aspect of the invention, the first glazing pane, the second glazing pane, the conductive layer, and the dielectric layer may each be substantially transparent or substantially translucent, and the variable position electrode may be substantially translucent or substantially opaque. The variable position electrode may include a color coating. One or more of the conductive layer and the dielectric layer may be a Low E coating. The further conductive layer of the variable position electrode may include one or more of a colored layer and a reflective layer. The further conductive layer of the variable position electrode may be a metal layer, and the metal layer may be a 100 to 500 Å thick layer of aluminum. The resilient layer of the variable position electrode may be a shrinkable polymer, and the shrinkable polymer may be polyethylenenapthalate (PEN), polyethyleneterephthalate (PET), or polyphenylene sulfide (PPS). The resilient layer of the variable position electrode may have a thickness of 1 to 5 μm.

Further in accordance with this aspect of the invention, the dielectric layer may be a low dissipation factor polymer, and the low dissipation factor polymer may be polypropylene, fluorinated ethylene propylene (FEP), or polytetrafluoroethylene (PTFE). The dielectric layer may have a thickness of 4 to 10 μm. The conductive layer beneath the dielectric layer may be a substantially transparent conductor, and the substantially transparent conductor may be indium tin oxide (ITO) or tin oxide (SnO_2). The conductive layer beneath the dielectric layer may have a thickness of 500 to 5000 Å.

Still further in accordance with the above aspect of the invention, the outer edge of the coiled spiral roll may be attached to the dielectric layer atop a location near an edge of the first glazing pane, and the insulated glazing unit may include a locking restraint that is located near an opposing edge of the first glazing pane so that when the variable position electrode unwinds, the locking restraint prevents a portion adjoining an inner edge of the coiled spiral roll from being rolled out. The locking restraint may be comprised of a conductive material. The locking restraint may include a low dissipation factor polymer coating, and the low dissipation factor polymer coating may be polypropylene, fluorinated ethylene propylene (FEP) or polytetrafluoroethylene (PTFE). The locking restraint may be hidden from view by the supporting structure.

A controllable radiation transmittance window may include an insulated glazing unit in accordance with the above aspect of the invention. One of the first glazing pane and the second glazing pane may be an outside window pane, and the other one of the first glazing pane and the second glazing pane may be an inner window pane.

A controllable radiation transmittance window may include a plurality of insulated glazing units each in accordance with the above aspect of the invention as well as a common switch operable to apply and remove the voltage between the first electrical lead and the second electrical lead in each of the plurality of insulated glazing units.

A controllable radiation transmittance door may include an insulated glazing unit in accordance with the above aspect of the invention.

A controllable radiation transmittance skylight may include an insulated glazing unit in accordance with the above aspect of the invention.

A controllable radiation transmittance moon roof may include an insulated glazing unit in accordance with the above aspect of the invention.

A controllable radiation transmittance canopy may include an insulated glazing unit in accordance with the above aspect of the invention.

According to a method of the invention, an insulated glazing unit having controllable radiation transmittance is fabricated. A first glazing pane is provided, and a conductive material is coated onto a given surface of the first glazing pane to form a conductive layer. A dielectric material is laminated atop the conductive layer to form a dielectric layer. A layered structure is provided that includes a polymer layer and a further conductive layer. A first edge of the layered structure is attached onto a mandrel with the first edge of the layered structure extending along a width of the layered structure and being attached to the mandrel along a length of its shaft, the layered structure thereby wrapping around the mandrel. The layered structure is heated to a temperature at which the polymer layer of the layered structure shrinks and causes the layered structure to form a tightly coiled spiral roll around the mandrel. An outer edge of the coiled spiral roll is affixed along a width thereof onto the dielectric layer. A first electrical lead is connected to the conductive layer of the variable position electrode, and a second electrical lead is connected to the conductive layer atop the inner surface of the first glazing pane. A voltage is applied between the first electrical lead and the second electrical lead to create a predetermined potential difference between the fixed position and variable position electrodes so that the variable position electrode unwinds and rolls out to allow removal of the mandrel. The first glazing pane and a second glazing pane are attached at their peripheries to a supporting structure such that the given surface of the first glazing pane and a given surface of the second glazing pane face each other and are spaced apart from each other, and the variable position electrode is disposed between the first glazing pane and the second glazing pane.

In accordance with the above method of the invention, the coating step may include one or more of physical deposition and vapor deposition. The coating step may include pyrolytic spraying of the conductive material onto the surface of the first glazing pane or rf sputtering of the conductive material onto the surface of the first glazing pane. The laminating step may include preheating the first glazing pane and then passing the first glazing pane and the dielectric material through a roll laminator, and the roll laminator may include a hot shoe or a hot roller. The affixing step may include applying a line of adhesive onto the dielectric layer and then affixing the outer end of the coiled spiral roll onto the line of adhesive.

According to another method of the invention, an insulated glazing unit having controllable radiation transmittance is fabricated. A first glazing pane is provided, and a conductive material is coated onto a given surface of the first glazing pane to form a conductive layer. A dielectric material is laminated atop the conductive layer to form a dielectric layer. A layered structure is provided that includes a polymer layer and a further conductive layer. Each of the edges of the layered structure is affixed onto the dielectric layer. All but one of the edges of the layered structure are released from the dielectric layer so that the layered structure wraps around itself. The layered structure is heated to a temperature at which the polymer layer of the layered structure shrinks and causes the layered structure to form a tightly coiled spiral roll. A first electrical lead is connected to the conductive layer of the variable position electrode, and a second electrical lead is connected to the conductive layer atop the inner surface of the first glazing pane. The first glazing pane and a second glazing pane are attached at their peripheries to a supporting structure such that the given surface of the first glazing pane and a given surface of the second glazing pane face each other and are spaced apart from each other, and the variable position electrode is disposed between the first glazing pane and the second glazing pane.

In accordance with the above method of the invention, the releasing step may include cutting the layered structure using a blade, cutting the layered structure using a laser, or chemically releasing all but the one of the edges of the layered structure from the dielectric layer.

According to yet another method of the invention, an insulated glazing unit having controllable radiation transmittance is fabricated. A first glazing pane is provided, and a conductive material is coated onto a given surface of the first glazing pane to form a conductive layer. A dielectric material is laminated atop the conductive layer to form a dielectric layer, and a layered structure that includes a polymer layer and a further conductive layer is provided. A line of adhesive is applied onto the dielectric layer. A flat counter weight is placed atop the layered structure and covers the area of the layered structure. An edge of the layered structure is positioned along a width thereof onto the line of adhesive to affix the outer edge of the layered structure to the dielectric layer. The flat counter weight is removed from atop the layered structure so that the layered structure wraps around itself. The layered structure is heated to a temperature at which the polymer layer of the layered structure shrinks and causes the layered structure to form a tightly coiled spiral roll. A first electrical lead is connected to the conductive layer of the variable position electrode, and a second electrical lead is connected to the conductive layer atop the inner surface of the first glazing pane. The first glazing pane and a second glazing pane are attached at their peripheries, and the resulting assembly is then attached to a supporting structure such that the given surface of the first glazing pane and a given surface of the second glazing pane face each other and are spaced apart from each other, and the variable position electrode is disposed between the first glazing pane and the second glazing pane.

In accordance with each of the above methods of the invention, the laminating step may include laminating a low dissipation factor polymer to form the dielectric layer, and the low dissipation factor polymer may be polypropylene, fluorinated ethylene propylene (FEP), polytetrafluoroethylene (PTFE), or other low dissipation polymers. The laminating step may form a dielectric layer having a thickness of 4 to 10 μm. The coating step may include coating a substantially transparent conductor to form the conductive layer, and the substantially transparent conductor may be indium tin oxide (ITO), tin oxide (SnO_2), or zinc oxide (ZnO). The coating step may form a conductive layer having a thickness of 500 to 5000 Å.

Further in accordance with each of the above methods of the invention, the step of providing a layered structure may include providing a color coating. The step of providing a layered structure may include providing a 100 to 500 Å thick metal layer as the further conductive layer, and the metal layer may be aluminum. The step of providing a layered structure may include providing a shrinkable polymer as the resilient layer, and the shrinkable polymer may be polyethylenenapthalate (PEN) or polyethyleneterephthalate (PET). The step of providing a layered structure may include providing a resilient layer having a thickness of 1 to 5 μm. At least one of the conductive material and the dielectric material may be a tinted or non-tinted Low E material.

The foregoing aspects, features and advantages of the present invention will be further appreciated when considered with reference to the following detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram showing a front (or rear) view of an insulated glazing unit (IGU) that includes an electropolymeric shutter according to an embodiment of the invention and depicting the shutter in a rolled-up state.

FIG. **2***a* is a diagram showing a cross-sectional view of the insulated glazing unit (IGU) of FIG. **1** taken along line A-A and depicting the electropolymeric shutter in a partially rolled out state.

FIG. **2***b* is a diagram showing a cross-sectional view of an IGU of the type shown in the type shown in FIG. **1** but depicting a pair of electropolymeric shutter in partially rolled-up states according to a further embodiment of the invention.

FIG. **3** is a diagram showing, in detail, a side view of an electropolymeric shutter attached to a glazing pane according to an embodiment of the invention and depicting the shutter in a rolled-up state.

FIG. **3***b* is a diagram showing, in detail, a side view of the electropolymeric shutter attached to a glazing pane of FIG. **3***a*, in a preliminary step in the fabrication method.

FIG. **4** is a diagram showing the electropolymeric shutter of FIG. **3** in a rolled out state.

DETAILED DESCRIPTION

The present invention overcomes the disadvantages of existing insulated glazing units (IGUs), such as are used currently in energy efficient windows, by incorporating an electrically controlled, extremely thin physical electropolymeric shutter between the glazing panes of the IGU. The electropolymeric shutter of the invention provides improvements in functionality, reliability and manufacturability over known electropolymeric shutter devices, for example, in the display pixels of existing electropolymeric display (EPD) technology, specifically by providing the glazing applications such as are described herein. Known shutter devices are described in U.S. Pat. No. 4,266,339 (titled "Method for Making Rolling Electrode for Electrostatic Device" and issued May 12, 1981 to Charles G. Kalt), U.S. Pat. No. 5,231,559 (titled "Full Color Light Modulating Capacitor" and issued Jul. 27, 1993 to Kalt, et al.), U.S. Pat. No. 5,519,565 (titled "Electromagnetic-Wave Modulating, Movable Electrode, Capacitor Elements" and issued May 21, 1996 to Kalt, et al.), U.S. Pat. No. 5,638,084 (titled "Lighting-Independent Color Video Display" and issued Jun. 10, 1994 to Kalt), U.S. Pat. No. 6,771,237 (titled "Variable Configuration Video Displays And Their Manufacture" and issued Aug. 3, 2004 to Kalt), and U.S. Pat. No. 6,692,646 (titled "Method of Manufacturing a Light Modulating Capacitor Array and Product" and issued Feb. 17, 2004 to Kalt, et al.), the disclosures of which are incorporated herein by reference.

The shutter is normally rolled up, but when an appropriate voltage is applied, the shutter rapidly rolls out to cover the entire glazing pane much like, for example, a traditional window shade. The rolled up shutter can have a very small diameter, which may be much smaller than the width of the space between the glazing panes, so that it can function between the panes and is essentially hidden when rolled up. The rolled out shutter adheres strongly to the window pane.

The electropolymeric shutter is preferably formed of an inexpensive polymer material. The polymer material is preferably coated with a reflective, conductive material and optionally coated with a colored material. By varying the thicknesses of the coatings, the shutter can be produced either to essentially fully block visible and/or infrared light or to partially block such light.

In an example of the invention, an electropolymeric shutter blocks essentially 100% of all impinging radiation and heat, thereby increasing the energy efficiency of the IGU over known approaches. Also preferably, the electropolymeric shutter is hidden from view when rolled up, thereby providing a higher quality IGU suitable for a window, door or skylight.

Preferably, the electropolymeric shutter of the invention lasts for many millions of roll outs and roll ups, thereby providing an operating life that is at least as long as that of the window, door or skylight in which the IGU of the invention may be used. Also, the shutter preferably rolls out and then rolls back up at extremely fast speeds, adding to its effectiveness when the IGU of the invention is used to provide energy efficiency and/or for privacy. Further, the electropolymeric shutter of the invention is simple to construct and preferably uses available, commodity-like materials which greatly reduces its manufacturing costs and greatly simplifies its manufacturing processes. As a result, the electropolymeric shutter of the invention may be manufactured at the same facility where a window, door or skylight IGU is manufactured.

An embodiment of an insulated glazing unit (IGU) **100** of the invention is shown in FIGS. **1** and **2***a*. FIG. **1** shows a front (or rear) view of the IGU **100**, and FIG. **2***a* shows a cross-sectional, side view of the IGU **100** taken along line A-A of FIG. **1**.

The insulated glazing unit **100** includes first and second glazing panes **120** which are attached at their periphery with a spacer **150** in-between them around their periphery. A support structure **102** surrounds the resulting first and second glazing pane assembly and is attached to the assembly at the periphery. The first and second glazing panes **120** are preferably made of a standard glass, such as is currently used for residential or commercial glazing applications, but alternatively may be comprised of any other known other rigid or flexible material such as polycarbonate, acrylic, glass reinforced polyester, or tempered glass. Any conventional or non-conventional thickness of glazing pane may be used, and the thicknesses of the two glazing panes do not need to be the same. Also, the support structure **102** may part of, for example, a window frame, door, skylight, moon roof, or canopy, but is not limited to only such applications.

An electropolymeric shutter **110** is disposed between the first and second glazing panes **120** and, preferably, is attached at one end to an inner surface of one of the first and second glazing panes **120** near the top of the support structure **102** by an adhesive layer **112**. The electropolymeric shutter **110** is shown fully rolled up in FIG. **1** and is shown partially rolled out in FIG. **2***a*. FIG. **1** shows an exposed electropolymeric shutter **110** and adhesive layer **112** for illustrative purposes. However, in most applications, the electropolymeric shutter **110** and the adhesive layer **112** are usually hidden by part of the support structure **102** so that the electropolymeric shutter is only seen when at least partially rolled out.

The diameter of a fully rolled up electropolymeric shutter is preferably about 1 to 5 mm but may be greater than 5 mm. However, for the electropolymeric shutter to quickly and repeatedly roll out and roll up, the diameter of the rolled up shutter should be no greater than the size of the space between the two glazing panes, which is typically about one-half inch.

A power supply **130** is provided that drives the electropolymeric shutter and is electrically connected to the shutter by lead **132** as well as to one of the glazing panes by lead **134**. Though the leads **132**,**134** are visible in the FIG. **1** for illustrative purposes, they are preferably hidden from view by the support structure **102**. The power supply **130** is preferably a simple compact structure that can be unobtrusively placed in a convenient location associated with the IGU and, optionally, also hidden from view. For example, the power supply may be a device structure about the size of a deck of cards or smaller. The power supply is preferably capable of providing an output voltage in the range of 100 to 500 V DC and may driven by an external AC or DC power supply or by a DC battery. However, a higher or lower output voltage may be needed depending on the fabrication parameters and materials that comprise the shutter and the layers of the glazing pane.

Preferably, the electropolymeric shutter **110** is in a rolled up state in the absence of an applied voltage, and rolls out when a voltage is applied, and rolls up again when the applied voltage is removed.

The manner in which the power supply **130** is controlled generally depends on the type of application in which the IGU is used. A manual on-off switch may be used to control the power supply and thus control the shutter. Alternatively, the power supply may be configured to be remotely controlled, such as by receiving infra-red, radio, microwave or other signals generated by a hand-held remote controller, to allow for remote operation of the shutter. A single switch may control only one IGU or may control a group of IGUs, such as all of the IGUs in a room or all of the IGUs along a given wall in a room. Further, the power supply may be configured to incorporate a processor and a network interface that would enable the shutter to be controlled from another location in a building, such as by a personal computer (PC) or the like using either a hard wired or wireless local network, or from another location, such as by an Internet connection over a telephone network, cellular network, cable network, etc.

The power supply **130** may include a radiation or heat sensor that controls the supply of voltage to the shutter and which may used in place of, or in combination with, the manually-controlled or remotely-controlled switch. Such a sensor can be configured to cause the shutter to roll out when a predetermined intensity level of solar radiation impinges on the IGU or to cause the shutter to roll up when the intensity level of the solar radiation impinging on the IGU drops below a predetermined level. Alternatively, the sensor may be configured to cause the shutter to roll out to either retain internal heat or prevent internal heating based on whether the room temperature or the outside temperature is above or below a predetermined value, or the sensor may be configured to roll up based on reached such a predetermined temperature value. Moreover, the sensor may be configured to cause the shutter to roll out or roll up based on a combination of the intensity of solar radiation and a measured temperature. An example of a known electrical control system for controlling variable transmittance windows is described in U.S. Pat. No. 7,085,609, titled “Variable Transmission Window Constructions” and issued Aug. 1, 2006 to Bechtel, et al., the disclosure of which is incorporated herein by reference.

Though the FIGS. **1** and **2** show a single electropolymeric shutter that rolls out to cover an entire glazing pane, other configurations may be used in which the IGU is comprised of more than one electropolymeric shutter and/or more than one glazing panes. As an example, the IGU may be formed of multiple glazing panes each of which has a respective electropolymeric shutter attached thereto **110**, **110'** attached thereto, as shown in FIG. **2***b* depicting IGU **100'**. Alternatively, the IGU may employ only a single glazing pane to which is attached multiple electropolymeric shutters which, when all of the shutters are rolled out, may completely cover the glazing pane. When multiple electropolymeric shutters are employed, the shutters may be controlled to act in unison, such as to provide the appearance of a single shutter, or the shutters may be individually controlled to roll out according to a predetermined pattern, such as by rolling out only the uppermost shutters.

Also, the glazing panes and the IGU are each shown in FIGS. **1** and **2***a* as being rectangular or square shaped. However, other shapes for the IGU and/or the glazing panes are also possible depending on the specific application of the IGU. In such applications, one or more electropolymeric shutters may be used and configured to cover either part or all of the glazing pane when rolled out. As an example, for windows with curved edges, the curved periphery can be covered by piecing together more than one electropolymeric shutter.

A locking restraint **114** is disposed at the bottom of the IGU **100** along its width and serves to prevent any unfurled portion of the electropolymeric shutter from contacting the glazing pane when the shutter is rolled out. Though the locking restraint **114** is visible in FIGS. **1** and **2***a* for illustrative purposes (as well as **114'** in FIG. **2***b*), it is preferably hidden behind the bottom of the support structure **102**. The locking restraint is preferably constructed of a conductive material, such as a metal or the like. The locking restraint may also be coated with a low dissipation factor polymer, such as polypropylene, fluorinated ethylene propylene (FEP) or polytetrafluoroethylene (PTFE).

An embodiment of an electropolymeric shutter **310** of the invention and its operation are depicted in greater detail in FIGS. **3***a* and **4**. FIG. **3***a* shows a side view of the electropolymeric shutter **310** in its rolled up state and also shows a portion of a glazing pane **320** of an IGU of the invention. FIG. **4** illustrates the electropolymeric shutter **310** and the glazing pane **320** in side view when the electropolymeric shutter is at least partially rolled out.

The glazing pane **320** is covered with a conductive layer **322** upon which is provided a dielectric layer **324**. Both the conductive material and the dielectric material are preferably transparent. The conductive layer **322** is electrically connected via a terminal **334** to, for example, the lead **134** of FIG. **1** and serves as a fixed electrode of a capacitor. The dielectric layer **324** serves as the dielectric of this capacitor.

The conductive layer **322** is typically a transparent conductor and, preferably, is a commonly available conductive material such as is used in the flat panel display industry. Among the transparent conductors used are indium tin oxide (ITO) and tin oxide (SnO_2), though other similar materials may alternatively be used. Preferably, the conductive layer **322** is about 500 to 5000 Å thick, though other thicknesses may be used depending on the conductor chosen for the conductive material and the desired application. Though examples of a transparent conductor are provided, a translucent conductor or other type conductor could be employed as the conductive layer.

The dielectric layer **324** is typically a transparent dielectric material, though a translucent dielectric material may alternatively be used. Preferably, the transparent dielectric material is a low dissipation factor polymer. Such commonly available polymers include polypropylene, fluorinated ethylene propylene (FEP), and polytetrafluoroethylene (PTFE), though other polymers may be used, Preferably, the thickness of the dielectric layer is about 4 to 10 μm, though other thicknesses may be used depending on the material chosen for the dielectric layer and the desired application. However, thinner dielectric layers typically reduce the reliability of the shutter whereas thicker dielectric layers typically require a too high applied voltage.

A low emissivity (low E) coating may also be provided for the glazing pane **320**. Because many Low E coatings are conductive, such Low E coatings may be used in place of the conductive layer **322**. Furthermore, some Low E coatings incorporate a silver material within a protective matrix and thus are insulators that may utilized as the dielectric layer **324**. Moreover, other Low E coatings use a protective overcoat atop a silver layer and may be substituted for both the conductive layer **322** and the dielectric layer **324**, thereby reducing the cost of manufacturing the IGU of the invention. Additionally, the standard processes used for manufacturing Low E coatings are able to accommodate a wide range of acceptable conductivities and are thus especially suitable for providing a Low E coating as the conductive layer.

The electropolymeric shutter **310** includes a resilient layer **316** upon which is disposed another conductive layer **318**. The resilient layer **316** is preferably formed from a shrinkable polymer such as polyethylenenapthalate (PEN) or polyethyleneterephthalate (PET), though other shrinkable polymers may be used. The polymer used for the resilient layer is preferably about 1 to 5 μm thick, but other thicknesses may be employed according to the polymer chosen and the intended application. However, thinner resilient layers typically reduce the reliability of the shutter whereas thicker resilient layers typically require higher applied voltages.

The conductive layer **318** may be made of a metal or a conducting non-metal and may be made to be reflective, so that the shutter essentially blocks the sun's visible and/or near visible radiation when rolled out, or made to partially block the sun's radiation. To provide a reflective or mirror appearance, the conductive layer **318** is preferably a reflective metal such as aluminum and is preferably about 100 to 500 Å thick, though a layer having a different thickness may be used based on the intended application. The preferred thickness range provides the most desired transmission variation. Thicknesses outside that range typically reduce the reliability of the electropolymeric shutter.

An optional coloring material **340** may be provided as a coating on the electropolymeric shutter. The coloring material may be used to give the shutter the appearance of a traditional window shade by employing a decorator color coating. Preferably, the reflective layer faces the outside of the window and the colored layer faces inside.

As FIG. **3***a* shows, the electropolymeric shutter **310** is ordinarily coiled as a spiral roll with the outer end of the spiral affixed by an adhesive layer **312** to the dielectric material **324** atop the glazing pane **320**. The conductive layer **318** is electrically connected via a terminal **332** to, for example, the lead **132** of FIG. **1** and serves as a variable electrode of a capacitor having the conductive material **322** as its fixed electrode and the dielectric material **324** as its dielectric.

When a voltage difference is provided between the variable electrode and the fixed electrode, namely, when a voltage is applied across the conductive layer **318** of the electropolymeric shutter **310** and the conductive material **322** above the glazing pane **320**, the variable electrode is pulled toward the fixed electrode by an electrostatic force created by the potential difference between the two electrodes. The pull on the variable electrode causes the coiled shutter to roll out, as FIG. **4** shows. The electrostatic force on the variable electrode causes the electropolymeric shutter to be held securely against the fixed electrode of the glazing pane. As a result, when the electropolymeric shutter includes a reflective layer, for example, the rolled out electropolymeric shutter prevents light or other radiation from passing through the IGU and thereby changes the overall function of the IGU from being transmissive to being reflective.

When the voltage difference between the variable electrode and the fixed electrode is removed, the electrostatic force on the variable electrode is likewise removed. The spring constant present in the resilient layer **316** of the electropolymeric shutter **310** causes the shutter to roll up back to its original, tightly wound position. Because movement of the electropolymeric shutter is controlled by a primarily capacitive circuit, current essentially only flows while the shutter is either rolling out or rolling up. As a result, the average power consumption of the electropolymeric shutter is extremely low.

The fabrication of the electropolymeric shutter of the invention and its assembly within an IGU is preferably carried out in a manner that ensures good adhesion between the electropolymeric shutter and the glazing unit, avoids wrinkles in the layers of the electropolymeric shutter, and provides an overall smooth appearance when the electropolymeric shutter is rolled out. The shutter is also preferably fabricated and assembled within the IGU in a manner that allows the shutter to operate reliably when rolled out or rolled up and to reliably repeat these operations numerous times. It is thus desirable to provide such methods of fabrication and assembly, and three such novel methods are now described.

A first method of the invention uses the natural curl of the layered structure, advantageously with a mandrel **400** in a novel manner to form the electropolymeric shutter and attach it to a glazing pane.

A glazing pane is prepared to receive the electropolymeric shutter. The glazing pane is first coated with a transparent conductor. The coating step may be carried out in a known manner, such as by pyrolytic spraying of conductive material onto a surface of the glazing pane or by rf sputtering of the conductive material onto the surface of the glazing pane. This coating may be the functional layer of a Low E glazing. Next, a dielectric layer is then formed atop the transparent conductor. Preferably, the dielectric layer, such as a low dissipation factor polymer, is laminated to the glazing pane without using any adhesive so that the glazing pane remains essentially clear. When polypropylene is used as a low dissipation factor polymer for the dielectric layer, a polypropylene layer is laminated to the glazing pane by first preheating the glazing pane and then passing the glazing pane and the polypropylene layer together through a roll laminator that uses a hot shoe or, preferably, a hot roller. Alternatively, when fluorinated ethylene propylene (FEP) or polytetrafluoroethylene (PTFE) is used as a low dissipation factor polymer for the dielectric layer, an FEP or PTFE layer is laminated to the glazing pane by pressing the FEP or PTFE layer onto the glazing pane in an air tight manner and then heating the FEP or PTFE layer and the glazing pane until the FEP or PTFE softens and adheres to the glazing pane.

The electropolymeric shutter is fabricated using a layered structure formed of at least a polymer layer and a conductive layer as described above. When using a mandrel, the layered structure is first held along its width edge to the length of the shaft of the mandrel **400** to which it naturally grabs onto because of its curl, as shown in FIG. **3***b*. The mandrel **400** and the held layered structure are then heated to at least a temperature at which the polymer layer of the layered structure is caused to shrink. The conductive layer of the layered structure, however, does not shrink as the polymer layer shrinks so that the layered structure is pulled by the shrinking polymer layer in a manner that causes the layered structure to more firmly coil around the mandrel **400** and thereby form a tightly coiled spiral roll, as shown in FIG. **3***a*. A line of adhesive is next applied to the dielectric layer atop the glazing pane, and then the outer width edge of the layered structure is affixed to the dielectric layer atop the glazing pane. Next, the electrical contacts or leads are electrically connected to the conductive layer of the layered structure and to the transparent conductor, and a voltage is applied to the two electrical leads to cause the layered structure to roll out and release the mandrel.

The glazing pane is then attached at its periphery to another glazing pane with the intervening spacer, and sealed with the electrical leads passing through the seal. The resulting glazing assembly is then affixed to the supporting structure. The electrical lead to the conductive layer of the layered structure and the electrical lead to the conductive layer atop the glazing pane are then traced along the inside of the supporting structure, such as behind the top and side portions of the supporting structure, to an internally-located power supply or through an opening in the supporting structure to an externally-located power supply. The supporting structure is assembled within the overall window frame. The contacts are configured in a manner such that electrical contact with the leads is maintained even if the glazing pane and its supporting structure is moved within the window frame. Incorporating a metallic (conducting) structure in the supporting structure and window frame facilitates the electrical contact.

Another method of fabricating the electropolymeric shutter avoids using a mandrel. A glazing pane is coated with a conductive layer and is laminated with a dielectric layer in the manner described above. An adhesive is next applied atop the dielectric layer along each of the edges of the glazing pane to have a “picture frame” shape on the glazing pane. A pre-stretched layered structure, formed of at least a polymer layer and another conductive layer, is provided as described previously, and all edges of the layered structure are then adhered to the dielectric layer atop the glazing pane. The layered structure is then released along all but one of its edges so that the pre-stretched layered structure naturally curls around itself in a manner similar to that described regarding the above method. The edges of the layered structure are preferably released by cutting the layered structure using a blade or a laser. Optionally, a sacrificial layer is provided between the layered structure and the dielectric layer to avoid damaging the dielectric layer while cutting the layered structure. Alternatively, the edges of the layered structure are chemically released from the dielectric layer.

The layered structure and the glazing pane are then heated in a manner similar to that described previously so that the polymer layer shrinks and causes the layered structure to more firmly coil around itself and form the tightly coiled spiral roll. The other glazing pane, electrical leads and supporting structure are then assembled in the manner described above to complete the IGU.

A further method of fabricating the electropolymeric shutter uses a flat counter weight that is preferably the same length and width as the electropolymeric shutter. A conductive layer is coated atop the glazing pane, and a dielectric layer is laminated atop the glazing pane, both in the manner described regarding the first method. A line of adhesive is then applied along one edge of the dielectric layer. The flat counter weight is placed atop the layered structure to cover at least the area of the layered structure, and a width edge of the layered structure is positioned onto the line of adhesive to affix the edge of the layered structure to the dielectric layer. The flat counter weight is then removed so that the layered structure wraps around itself, and the layered structure and the glazing pane are heated as described above to form the tightly coiled spiral roll of the electropolymeric shutter. The remaining steps are carried out as set out above.

In addition to the three related methods described above, variations of these methods are also possible within the scope of the invention.

The incorporation of the electropolymeric shutter within an IGU according to the invention provides an IGU having improved energy efficiency. Additionally, the electropolymeric shutter and IGU of the invention may be used for various privacy applications by modifying the thickness of its conductive layer and/or the thickness of any coloring material used so that the IGU becomes translucent or fully opaque when the electropolymeric shutter rolls out.

The electropolymeric shutter and IGU of the invention may be used in any one of numerous applications in which IGUs are ordinarily used or in which controllable privacy is desired. The electropolymeric shutter and IGU of the invention may be used as an outside facing window, as an internally located window such as along a conference room, as a thermal door that is exposed to the outside, or as an optically clear door used inside. Moreover, the electropolymeric shutter and IGU of the invention may be incorporated into a skylight or other such window-like overhead structures used in a residential, commercial, or industrial building. Additionally, the electropolymeric shutter and IGU of the invention may be used in a motor vehicle, such as to provide a moon roof or the like, may be used in a commercial, industrial or military ground or sea vehicle, or may be used in an aircraft.

Also, the structure of the electropolymeric shutter and IGU of the invention and the manufacturing methods of the invention that are described above may be readily be varied to accommodate other possible applications that require simple changes without departing from the scope of the invention. The underlying principles of the invention remain the same in such applications.

Although the invention herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present invention. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

The invention claimed is:

1. A method of fabricating an insulated glazing unit having controllable radiation transmittance, said method comprising:

- providing a first glazing pane;
- coating a conductive material onto a given surface of the first glazing pane to form a conductive layer, thereby forming a fixed position electrode;
- laminating a dielectric material atop the conductive layer to form a dielectric layer;
- providing a layered structure that includes a polymer layer and a further conductive layer;
- holding a first edge of the layered structure onto a mandrel, the first edge of the layered structure extending along substantially the entire width of the first glazing pane and being held to the mandrel along a length of its shaft, the layered structure thereby wrapping around the mandrel;
- heating the layered structure to a temperature at which the polymer layer of the layered structure shrinks and causes the layered structure to form a variable position electrode in the form of a tightly coiled spiral roll around the mandrel;
- affixing an outer edge of the variable position electrode along a width thereof onto the dielectric layer;
- removing the mandrel from the layered structure; and
- attaching the first glazing pane and a second glazing pane to a spacer at their peripheries such that the given surface of the first glazing pane and a given surface of the second glazing pane face each other and are spaced apart from each other, the variable position electrode being disposed between the first glazing pane and the second glazing pane.

2. A method according to claim **1**, wherein said coating step includes one or more of physical deposition and vapor deposition.

3. A method according to claim **1**, wherein said coating step includes pyrolytic spraying of the conductive material onto the surface of the first glazing pane or rf sputtering the conductive material onto the surface of the first glazing pane.

4. A method according to claim **1**, wherein said laminating step includes preheating the first glazing pane and then passing the first glazing pane and the dielectric material through a roll laminator.

5. A method according to claim **1**, wherein said affixing step includes applying a line of adhesive onto the dielectric layer and then affixing the outer end of the coiled spiral roll onto the line of adhesive.

6. A method according to claim **1**, wherein said laminating step includes laminating a low dissipation factor polymer to form the dielectric layer.

7. A method according to claim **6**, wherein the low dissipation factor polymer is selected from the group consisting of polypropylene, fluorinated ethylene propylene (FEP), and polytetrafluoroethylene (PTFE).

8. A method according to claim **1**, wherein said laminating step forms a dielectric layer having a thickness of approximately 4 to 10 μm, or greater.

9. A method according to claim **1**, wherein said coating step includes coating a substantially transparent conductor to form the conductive layer.

10. A method according to claim **9**, wherein the substantially transparent conductor is selected from the group consisting of indium tin oxide (ITO), tin oxide (SnO_2), and zinc oxide (ZnO).

11. A method according to claim **1**, wherein said coating step forms a conductive layer having a thickness of approximately 500 to 5000 Å.

12. A method according to claim **1**, wherein said step of providing a layered structure includes providing a color coating.

13. A method according to claim **1**, wherein said step of providing a layered structure includes providing a reflective layer as the further conductive layer.

14. A method according to claim **1**, wherein said step of providing a layered structure includes providing an approximately 100 to 500 Å thick metal layer as the further conductive layer.

15. A method according to claim **14**, wherein the metal layer is aluminum.

16. A method according to claim **1**, wherein said step of providing a layered structure includes providing a shrinkable polymer as the polymer layer.

17. A method according to claim **16**, wherein the shrinkable polymer is selected from the group consisting of polyethylenenapthalate (PEN), polyethyleneterephthalate (PET), and polyphenylene sulfide (PPS).

18. A method according to claim **1**, wherein said step of providing a layered structure includes providing a polymer layer having a thickness of 1 μm or greater.

19. A method according to claim **1**, wherein at least one of the conductive material and the dielectric material is a tinted Low E material or a non-tinted Low E material.

20. A method according to claim **1**, further comprising attaching the insulated glazing unit to a supporting structure.

21. A method according to claim **20**, wherein said support structure is a support structure for one of a window, door, skylight, moon roof, canopy, ground vehicle, sea vehicle, or aircraft.

22. A method according to claim 1, wherein the mandrel is removed by unwinding the layered structure.

23. A method according to claim 1, wherein the mandrel is removed by applying a voltage between the further conductive layer of the variable position electrode and the fixed position electrode to create a predetermined potential difference between the fixed position electrode and the variable position electrode so that the variable position electrode unwinds and rolls out to allow removal of the mandrel.

24. A method according to claim 23, further comprising the step of attaching a power supply between the further conductive layer of the variable position electrode and the fixed position electrode.

25. A method according to claim 4, wherein the roll laminator includes a hot shoe or a hot roller.

26. A method according to claim 1, further comprising attaching a first lead to the conductive layer of the variable position electrode and a second lead to the conductive layer atop the inner surface of the first glazing pane.

27. A method according to claim 26, further comprising the step of attaching a power supply between the first lead and the second lead.

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